DEPARTMENT OF THE ARMY
CORPS OF ENGINEERS

THE

BULLETIN

OF THE

BEACH EROSION BOARD

OFFICE, CHIEF OF ENGINEERS
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a,b = distances along y_c-axis to adjacent contours

c_a, c_b = wave velocities at adjacent contours

κ_c = curvature of contour

$\Delta\phi$ = angle included by tangents to contour

m = length of chord connecting points of tangency

θ = angle between integral curve and s-axis

κ_β = curvature of integral curve

h = depth of water

L_o = wave length in deep water

κ = curvature of wave crest

c_o = wave velocity in deep water

λ = parameter depending on p and q

Introduction

The refraction factor, K, which is a linear measure of the effect of refraction on the height of water waves, has been calculated by measuring the separation distance between two neighboring rays (orthogonals) on a refraction diagram. For later convenience define a ray separation factor

$$\beta = \gamma/\gamma_o,$$

where γ_o designates the distance between the given ray and an adjacent ray at some initial depth, and γ the distance between the rays at an arbitrary depth (Fig. 1). The refraction factor is then,

$$K = |\beta|^{-1/2} \ ; \quad K_b = |\beta|^{-1/3}$$

depending on whether the arbitrary depth is outside or at the depth of breaking. (Munk and Traylor, 1947).

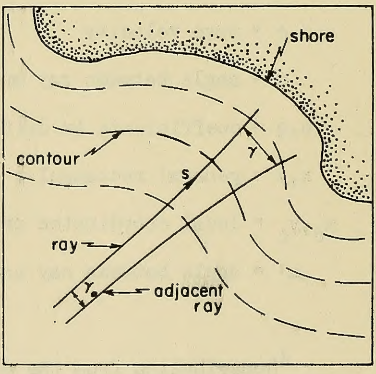


Fig. I

Values of β or K determined from measured values of γ_0 and γ do not apply to a point on either ray but to some point between the two rays. Where rays diverge greatly over underwater canyons, it is not always possible to construct rays close enough together in deep water to avoid uncertainty in the value of K in shallow water. On the other hand, two rays may approach so closely over an underwater ridge that minor inaccuracies in ray position will introduce gross errors in the measured separation distance γ .

The difficulties are avoided if the adjacent ray is imagined to be as close as desired to the given ray, i.e., if β is regarded as the ratio between two infinitesimal distances γ and γ_0 . With this interpretation it is no longer possible or necessary to construct the adjacent ray and to measure γ and γ_0 . The two rays will still diverge or converge according to the orientation, spacing and curvature of the depth contours in a manner similar to rays which are separated by a finite distance. The dependence of β on the ray path and contours has been evolved.

The present paper illustrates a method for calculating β, and therefore K, in terms of distance s measured along the ray and its infinitesimally close neighbor. The basic relationship is a second order differential equation. The coefficients of the equation must be computed from the spacing, orientation, and curvature of the contours traversed by the ray. The problem, then is to calculate the value of β as a function of s along the ray from the differential equation by use of a graphical or numerical method.

Results from Theory

It is assumed that the wave velocity, c, is known from the depth contours and that a ray has been constructed by the crestless method (Johnson, O'Brien, and Isaacs, 1948; Saville and Kaplan, 1952; Arthur, Munk and Isaacs, 1952). Let s denote the arc length along the ray and α the angle between the ray and the x-axis (Fig. 2). By proceeding from basic principles of refraction, it may be shown (Munk and Arthur, 1952) that $\beta = \beta(s)$ is a solution of the ordinary second order differential equation

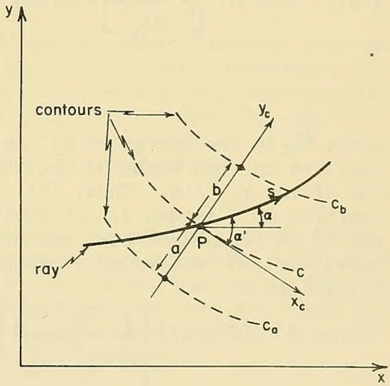


Fig. 2

$$\frac{D^2\beta}{Ds^2} + p\frac{D\beta}{Ds} + q\beta = 0, \qquad (1)$$

where

$$p(s) = -(\cos\alpha)\left[\frac{1}{c}\frac{\partial c}{\partial x}\right] - (\sin\alpha)\left[\frac{1}{c}\frac{\partial c}{\partial y}\right], \tag{2a,b}$$

$$q(s) = (\sin^2\alpha)\left[\frac{1}{c}\frac{\partial^2 c}{\partial x^2}\right] - 2(\sin\alpha\cos\alpha)\left[\frac{1}{c}\frac{\partial^2 c}{\partial x\,\partial y}\right] + (\cos^2\alpha)\left[\frac{1}{c}\frac{\partial^2 c}{\partial y^2}\right],$$

and where the symbol D/Ds denotes differentiation with respect to the arc length s along the ray. In general, p and q are not known analytically, but they can be computed at discrete points along the ray if the depth contours are labelled in terms of wave velocity c. Equations (2a,b) show that p and q depend upon α and c and the first and second derivatives of c, i.e., upon the properties of the contours mentioned previously. After p and q are determined, an approximate solution for β along the ray may then be obtained from (1) by a method due to Kelvin.

Determination of Coefficients p and q

Values of p and q at any point P on the ray in terms of a local coordinate system (x_c, y_c) oriented with respect to the contour at P (Fig. 2) are (Munk and Arthur, 1952)

$$p(s) = -(\sin\alpha')\left[\frac{1}{c}\frac{\partial c}{\partial y_c}\right] \tag{2c,d}$$

$$q(s) = (\cos^2\alpha')\left[\frac{1}{c}\frac{\partial^2 c}{\partial y_c^2}\right] - 2(\sin\alpha'\cos\alpha')\left[\frac{1}{c}\frac{\partial^2 c}{\partial x_c\,\partial y_c}\right] - (\sin^2\alpha')\left[\frac{K_c}{c}\frac{\partial c}{\partial y_c}\right],$$

where K_c is the curvature of the contour at point P. The curvature is positive in sign when the contour is concave as viewed from the positive end of the y_c-axis. Thus, the curvature of the contour at point P is positive in Figure 2. If derivatives are computed from finite differences and if it is assumed that contours in the vicinity of P have constant curvature and centers of curvature on the y_c-axis, then the approximate values are

$$p \doteq -(\sin\alpha')\left[\frac{1}{c}\;\frac{c_b - c_a}{a + b}\right]$$

$$q \doteq (\cos^2\alpha')\left[\frac{1}{c}\;\frac{\dfrac{c_b - c}{b} - \dfrac{c - c_a}{a}}{\dfrac{a+b}{2}}\right] + K_c\, p \sin\alpha' \; . \tag{3a,b}$$

In (3a,b), the quantities a and b denote the distances along the y_c-axis

from point P to adjacent contours with wave velocities c_a and c_b, respectively (see Fig. 2).

If the contours are straight, the second term on the right-hand side of (3b) is zero ($K_c = 0$) and if c varies linearly along y_c, the first term is zero. The curvature of the contour is approximated from a measurement of the angle, $\Delta\phi$, included by two tangents to the contour (Fig. 3), and of the length, m, of the chord connecting the points of tangency, since

$$K_c \doteq \frac{\cos\frac{\Delta\phi}{2}}{m/2} \tag{4}$$

The derivation of (4) assumes that the tangents include a section of the contour of constant curvature.

By application of (3a,b) and (4), the values of p and q at points of intersection of the ray and successive contours are obtained.

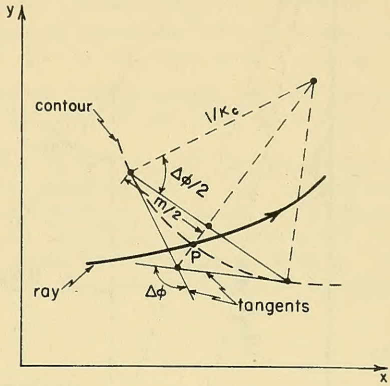


Fig. 3

Solution for β by Kelvin's Method

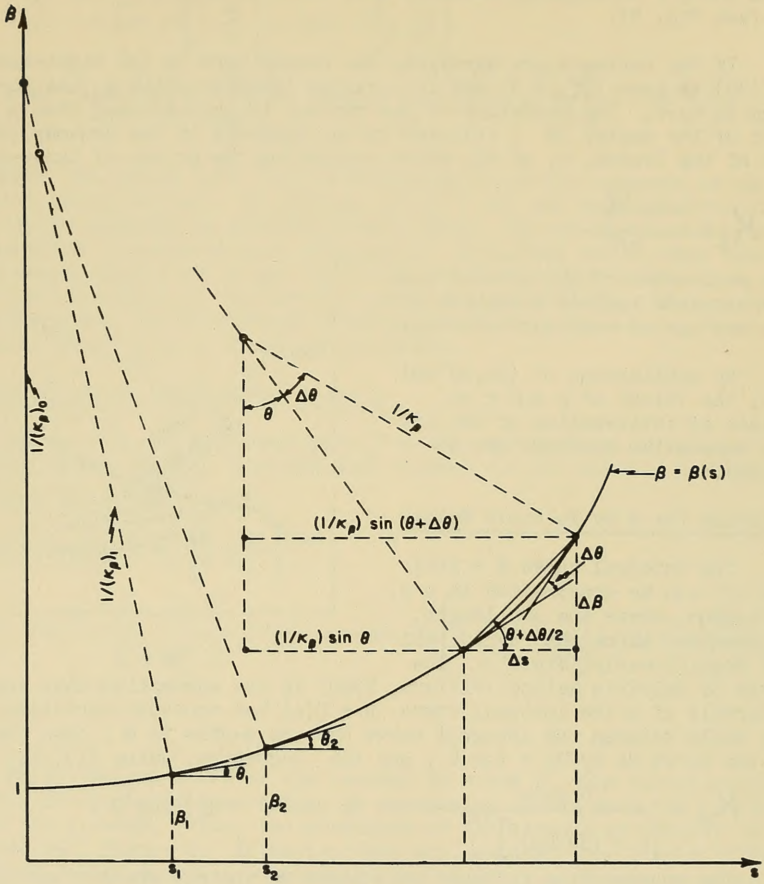
The integral curve $\beta = \beta(s)$ for (1) can be constructed in a β, s-diagram, where the arc length, s, measured along the ray is laid out rectilinearly (Fig. 4). The basis of Kelvin's method (Willers, 1948) is the assumption that over small intervals of s the integral curve $\beta = \beta(s)$ has constant curvature. If the angle between the integral curve and the s-axis is θ, then the slope of the curve is $D\beta/Ds = \tan\theta$, and the curvature, using (1), is

$$K_\beta = \frac{D^2\beta/Ds^2}{\left[1 + (D\beta/Ds)^2\right]^{3/2}} = -(p\tan\theta + q\beta)\cos^3\theta \, . \tag{5}$$

The construction is begun at a point on the ray where β and $D\beta/Ds$ are known. Usually this is a point in deep water, say where the ratio of depth h to deep water wave length L_o is $h/L_o = 0.5$. Along the ray to this point the effects of refraction are usually negligible, so that $\beta = 1$ and $d\beta/Ds = 0$. The construction may be started at any point, however, if the value of β and the curvature, K, of the wave crest are known since

$$\frac{1}{\beta}\frac{D\beta}{Ds} = K \, . \tag{6}$$

It is convenient to take s = 0 at the initial point. The values of coefficients p and q are computed at the initial point by the method of the previous section using (3a,b). The value of $(K_\beta)_o$ at the initial point



β
1
$1/(\kappa_\beta)_0$
$1/(\kappa_\beta)_1$
θ
Δθ
$1/\kappa_\beta$
β = β(s)
$(1/\kappa_\beta)\sin(\theta+\Delta\theta)$
Δθ
Δβ
$(1/\kappa_\beta)\sin\theta$
θ+Δθ/2
Δs
θ_2
θ_1
β_1
β_2
s_1
s_2
s

Fig. 4

is then computed from (5), and an arc of radius $1/(K_\beta)_o$ is drawn from point $s = 0$, $\beta = 1$ on the β , s-diagram. The center of curvature lies on a line perpendicular to the known tangent direction, $\tan \theta_o = D\beta/Ds = 0$, i.e., on the β-axis.

The distance $s = s_1$ along the ray to the next contour is obtained, approximately, by measuring the length of the chord or tangents drawn in the ray construction. The circular arc in the β, s-diagram is extended to $s = s_1$, and the value $\beta = \beta_1$ is read. The angle $\theta = \theta_1$ is obtained from the direction of the tangent at $s = s_1$, $\beta = \beta_1$, and then $(K_\beta)_1$ is computed from (5) introducing β_1, θ_1, and the values of p and q appropriate to the point $s = s_1$ on the ray. A second arc of radius $1/(K_\beta)_1$ is smoothly joined to the first by taking the center of curvature on a line perpendicular to the tangent at $s = s_1$, $\beta = \beta_1$. The arc is extended to $s = s_2$, the distance along the ray to the next contour intersection, and the process is repeated. The integral curve $\beta = \beta(s)$ for (1) is thus approximated.

The application of Kelvin's method in solving (1) parallels the use of the method as a basis for the direct construction of the ray (Arthur, Munk, and Isaacs, 1952). As in ray construction, the radii of curvature may be large, and it is more suitable to simply construct the chord or equal tangents to the circular arc as shown to the right in Fig. 4. The angular change $\Delta\theta$, which is required for the construction, is calculated from

$$\sin(\theta + \Delta\theta) = K_\beta . \Delta s + \sin \theta , \qquad (7)$$

a relationship which follows from the geometry of the figure.

For example, knowing θ_1 and $(K_\beta)_1$ at $s = s_1$ in Fig. 4, the angular change $\Delta\theta_1$ for the interval $\Delta s_1 = s_2 - s_1$ is calculable from (7) written in the form

$$\Delta\theta_1 = \sin^{-1} \left[(K_\beta)_1 \cdot \Delta s_1 + \sin \theta_1 \right] - \theta_1 .$$

The chord or equal tangents are constructed from s_1, β_1 and their intersection with the line $s = s_2$ gives $\beta = \beta_2$. The integral curve at s_2, β_2 makes an angle $\theta_2 = \theta_1 + \Delta\theta_1$ with the direction of the s-axis.

If desired, the graphical construction can be avoided and the change $\Delta\beta$ calculated from

$$\Delta\beta = \Delta s \ . \ \tan \left(\theta + \frac{\Delta\theta}{2}\right) \qquad (8)$$

Equations (7) and (8) are employed in the example which follows.

Example: An analytic example has been selected in order that the approximate method of solution for β outlined above may be compared to an exact solution. Assume an underwater trough with straight axis (Fig. 5, lower) along which

$$p = 0.1/L_o; \quad q = -0.1/L_o^2 , \tag{9a,b}$$

where L_o is the deep water wave length. The straight axis is obviously a ray, along which $\beta = \beta(s)$ may be determined. Actually, the dimensionless distance s/L_o is used. From (9a,b) and (2c,d), it may be shown that along the axial ray

$$c/c_o = e^{-0.1s/L_o} ; \; \mathcal{K}_c = -1/L_o \tag{10a,b}$$

where c_o is the deep water wave velocity. The contours (dashed lines in Fig. 5) have been drawn by extending tangents from the ends of circular arcs each of radius L_o and each subtending an angle of 60°. Values of c/c_o and corresponding values of relative depth h/L_o are indicated.

Successive values of $\Delta\theta$ and $\Delta\beta$ have been calculated along the axial ray using Kelvin's method as a basis. Values of the variables are shown in Table 1. The resulting points $\beta, s/L_o$ have been plotted (Fig. 5, upper), and a smooth curve drawn through them. The constant values of p and q given in (9a,b) have been used in the computation. However, determinations of p and q have also been made using (3a,b) and (4), and the values were within a few percent of the exact values (9a,b).

For comparison, a second ray has been constructed by the crestless method as close to the axial ray as the scale of the enlargement ($L_o = 1$ inch) permitted. The second ray has not been drawn beyond the point where the contours become straight. The value of K computed from measurements of the separation of the two rays at $c/c_o = 1.0$ and at $c/c_o = 0.5$ is 0.48, which is to be compared to the exact value 0.51.

The exact solution of (1) along the straight axial ray with constant values (9a,b) of p and q is well known and, if the initial conditions $\beta_o = 1$, $(D\beta/Ds)_o = 0$ are used, takes the form (Munk and Arthur, 1952)

$$\beta = e^{-ps/2}\left[\cosh(\lambda s) + \frac{p}{2\lambda}\sinh(\lambda s)\right], \tag{11}$$

where $p/2 = 0.05/L_o$ and $\lambda^2 = (p/2)^2 - q = 0.1025/L_o^2$. Exact values of K for certain values of s are tabulated.

Discussion

The example indicates the accuracy which may be expected in the determination of refraction factor, K , along a single ray by Kelvin's method. The accuracy, of course, decreases over those sections of the ray for which there is large change in curvature, $\mathcal{K}_\beta$, of the curve $\beta = \beta(s)$

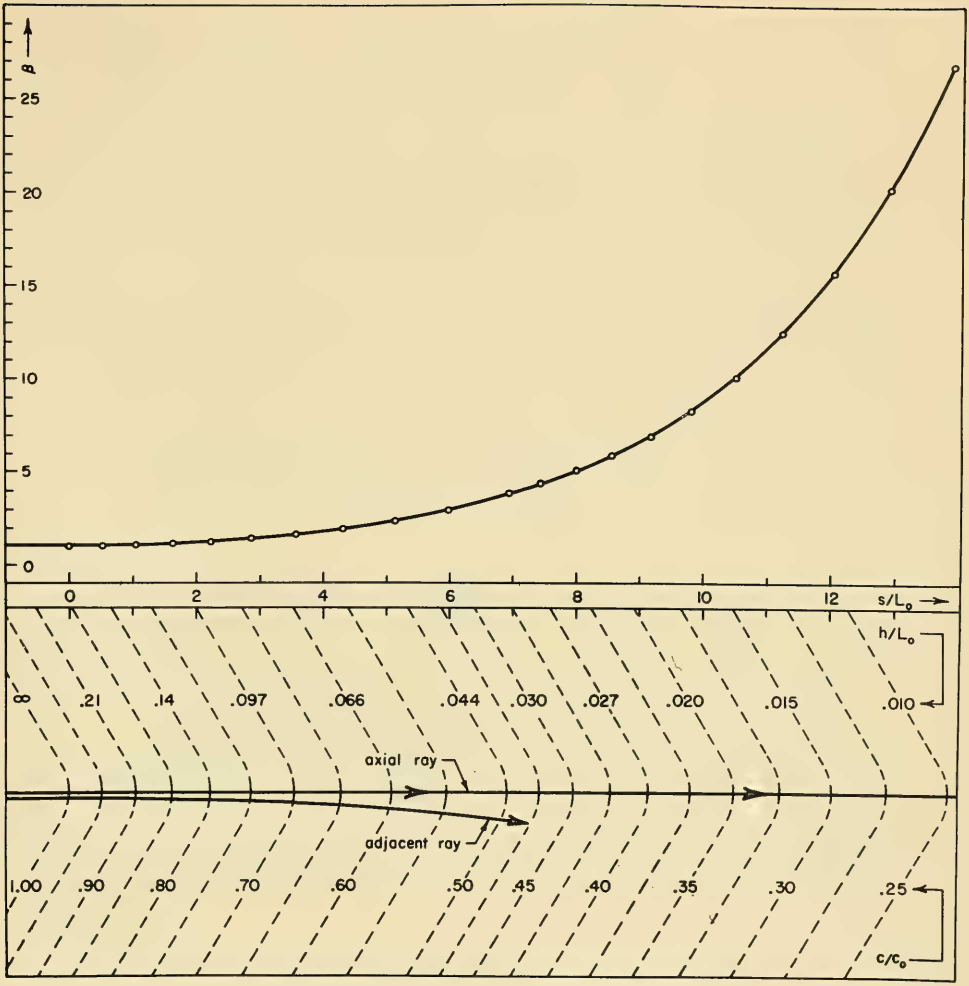

β
25
20
15
10
5
0
0
2
4
6
8
10
12
s/L₀
h/L₀
∞
.21
.14
.097
.066
.044
.030
.027
.020
.015
.010
axial ray
adjacent ray
1.00
.90
.80
.70
.60
.50
.45
.40
.35
.30
.25
c/c₀

Fig. 5

Table 1

c/c_o	s/L_o	pL_o	qL_o^2	θ	β	K_β	$\Delta\theta$	$\Delta\beta$	K	K (exact)
1.000	0.000	0.1	-0.1	0° 00'	1.000	0.1000	2° 56'	0.0131	1.00	1.00
0.950	0.513	0.1	-0.1	2° 56'	1.013	0.0959	2° 59'	0.0419	0.99	
0.900	1.054	0.1	-0.1	5° 55'	1.055	0.0937	3° 06'	0.0749	0.97	
0.850	1.625	0.1	-0.1	9° 01'	1.130	0.0936	3° 18'	0.1142	0.94	
0.800	2.231	0.1	-0.1	12° 19'	1.244	0.0957	3° 39'	0.1628	0.90	
0.750	2.877	0.1	-0.1	15° 58'	1.407	0.0995	4° 09'	0.225	0.84	
0.700	3.567	0.1	-0.1	20° 07'	1.632	0.1048	4° 49'	0.307	0.78	
0.650	4.308	0.1	-0.1	24° 56'	1.939	0.1100	5° 42'	0.422	0.72	
0.600	5.108	0.1	-0.1	30° 38'	2.361	0.1125	6° 47'	0.587	0.65	
0.550	5.978	0.1	-0.1	37° 25'	2.948	0.1094	7° 58'	0.840	0.58	
0.500	6.931	0.1	-0.1	45° 23'	3.788	0.0960	4° 10'	0.559	0.51	0.51
0.475	7.444	0.1	-0.1	49° 33'	4.347	0.0867	4° 20'	0.685	0.48	
0.450	7.985	0.1	-0.1	53° 53'	5.032	0.0748	4° 24'	0.849	0.45	
0.425	8.556	0.1	-0.1	58° 17'	5.881	0.0620	4° 22'	1.072	0.41	
0.400	9.163	0.1	-0.1	62° 39'	6.953	0.0485	4° 12'	1.368	0.38	0.38
0.375	9.808	0.1	-0.1	66° 51'	8.321	0.0363	3° 58'	1.782	0.35	
0.350	10.498	0.1	-0.1	70° 49'	10.102	0.0255	3° 38'	2.37	0.32	
0.325	11.239	0.1	-0.1	74° 27'	12.47	0.0170	3° 14'	3.23	0.29	
0.300	12.040	0.1	-0.1	77° 41'	15.70	0.0107	2° 49'	4.51	0.25	
0.275	12.910	0.1	-0.1	80° 30'	20.21	0.0064	2° 26'	6.55	0.22	
0.250	13.863	0.1	-0.1		26.76				0.19	0.20

from one interval to the next. Decreasing the interval, as was done in the example for $c/c_o < 0.5$, and interpolating contours, if necessary, will improve the accuracy.

Since exact values of p and q from (9a,b) were used in the example, there is no indication of the effect of inaccuracies introduced by (3a,b) and (4). Some indication of the effect of errors in p and q may be obtained from (11). If, for $c/c_o = 0.25$, the values of p and q differ by 10 percent and 15 percent, respectively, from values (9a,b), the value of K changes by less than 15 percent.

The calculation of refraction factor along a ray has an advantage when the depth and wave velocity are expressed analytically, because any desired degree of precision may be achieved. This is not the case if the usual method of constructing an adjacent ray and measuring the separation distance is utilized. As mentioned previously, the latter method permits determination only of a sort of "average" value of K appropriate to the interval between the rays. There is always a physical limitation to the proximity at which an adjacent ray may be constructed. In Figure 5, it does not seem useful to continue the adjacent ray farther, because it has reached a region where the curvature and orientation of the contours is entirely different from along the axial ray.

The calculation of K along a ray is more time consuming than the usual method involving construction of an adjacent ray. For this reason, the usual method would appear to be preferable for complex underwater topography where the depth is not known analytically but only from bathymetric charts. An exception occurs where rays converge or diverge rapidly as over underwater ridges or troughs, for under these conditions values of K from the usual method may differ greatly from precise values which apply to a point on a ray. It should be mentioned that it is just these circumstances for which the applicability of ray theory and refraction factors is most questionable. However, the present remarks have been concerned entirely with the determination of refraction factors rather than their applicability. Values of K are correctly calculated by the present method even in the region of a caustic, but the breakdown of the approximations of ray theory prevents valid determinations of wave height from refraction factors under these circumstances.

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PROGRESS REPORTS ON RESEARCH SPONSORED BY THE BEACH EROSION BOARD

Abstracts from progress reports on several research contracts in force between universities or other institutions and the Beach Erosion Board, together with brief statements as to the status of research projects being prosecuted in the laboratory of the Beach Erosion Board, are presented as follows:

I. University of California, Contract No. DA-49-055-eng-8

A. Status Report No. 8, 1 Feb through 31 Mar 1953

This report pertains to the origin of sand upon beaches, especially with reference to the beaches of Southern California.

The primary object of the present phase of work on the contract is to drill holes through the sand fill west of Santa Barbara breakwater to procure undisturbed samples of the sand and of the offshore sediments that were beneath the water just prior to the time the fill was deposited. These studies are designed to provide information on the nature of the sediments under different conditions of transport of sand in shallow waters adjacent to the beach. Ordinarily core samples of such offshore sediments would have to be obtained with the aid of a drilling barge, but at Santa Barbara, where the offshore area was covered by fill following the construction of the breakwater, samples of the offshore sand can be obtained by drilling through the fill by an ordinary well drilling rig.

During the past two months a series of undisturbed core samples were obtained from seven holes in the area of fill west of the breakwater. The samples extend to more than 500 feet seaward from the original shore line and for approximately one-fourth mile along the beach parallel to the shore. The holes ranged in depth from 20 to 30 feet and bottomed in bed rock, of Pleistocene sand and clay on the east part of the fill and Miocene shale on the west part. The samples were obtained by means of a special underwater core sampler designed by Dames and Moore, Consulting Engineers, of San Francisco and Los Angeles. This device procures drive samples 10 inches in length and 2 inches in diameter. The samples were collected in thin wall brass cylinders and were sealed with paraffin to conserve the original content of water. Samples were taken at intervals of 2 to 3 feet. The laboratory study of the material is now in progress.

B. Status Report No. 9, 1 April through 31 May 1953

The 60 core samples of beach material from the filled area west of the Santa Barbara breakwater collected during March are now in the process of analysis. The cores have all been opened, photographed, and more than 200 samples removed for mechanical analyses. The program of analysis is about 50 percent complete. Preliminary microscopical examination of the cores has also been made. One half of each core has been saved for supplemental work which may be needed after the present series of studies has been completed.

Work contemplated during June and July. The mechanical analysis of the samples will be completed, the results compiled statistically, and other studies initiated upon the basis of the results obtained.

II. Scripps Institution of Oceanography, Quarterly Progress Report No. 15, January-March 1953.

Analyses of the total heavy mineral content of the sediments from the March 1950 survey were completed this quarter. The areal distribution pattern of heavy-minerals for the March survey is similar to that of the August 1949 survey, but differs somewhat as to detail.

Experimental measurements of the effects of accelerative forces on the orbital current meter have been applied to theoretical velocity distributions. The relatively small magnitude of accelerative terms in these theoretical cases suggests that accelerative terms are also small in the case of actual waves outside of the breaker zone. Generally speaking, the form of the velocity distribution curves obtained in the field shows good agreement with the theoretical distributions.

The program of underwater survey using a datum obtained by placing reference rods on the bottom is being expanded. New and larger steel rods are being used. A new method of locating the general area of the rods from the surface has been developed.

On 5 March a survey showed that a considerable slide had occurred in South Branch of Scripps Canyon, the first slide to have taken place in this particular area since 25 December 1951. This interval is considerably longer than previous intervals between slides. The maximum deepening was approximately 11 feet, near the head of the branch, where the depth had been 16 feet. At about 120 feet farther down the axis the depth increase had diminished to about 3 feet. Some change is also indicated in the adjacent branch, and in one profile a small valley, about 3 feet deep, developed along with a general deepening of the area by several feet, so that the shape of the profile is considerably altered.

A manuscript which presents the details of a sample calculation of wave refraction along a single ray (orthogonal) has been prepared.

III. New York University Second Quarterly Progress Report for period 1 March to 31 May 1953.

Hindcast Data - Checks of a wave spectrum forecasting method as developed from the theoretical spectra derived by Prof. Neumann are being made against situations in which they can be checked off by observations prior to preparing the statistical hindcasts.

Three years of 6 hourly weather maps have been assembled and work will begin soon on the actual task of preparing the hindcasts.

Wave Analyzer - After trips to NRL and NACA to view current spectral analyzers, two papers were submitted to the Board for review. The first paper discussed the design of the optimum filters. The second paper discussed the overall design of the analyzer which is based on a heterodyne principle which will eliminate many of the difficulties of current analyzer designs.

Conferences with the Board staff cleared up some of the features of the analyzer and plans were made to proceed with its construction. The component parts have been ordered, and work has begun.

IV. The Agricultural and Mechanical College of Texas, Quarterly Report for Period ending 31 March 1953.

The progress made during the first three quarters of this contract period has been summarized in the Quarterly Report for the period ending December 31, 1952 and dated January 15, 1953.

During this quarter of the contract period, the following progress was made.

1. Field Operations. No additional wave data was obtained during the fourth quarter. This was due to a temporary abandonment of the Pure Oil site and the facilities available there. During the last week of January, when the driller was bringing in a fifth well on the Pure Oil Structure A in Block 32, a fire broke out and completely destroyed the drilling platform. All Research Foundation instruments had to be removed from the instrument shack located on the Quarters platform. This included two of the wave recorders and pressure heads furnished the Research Foundation by the Beach Erosion Board. One of the units was installed permanently at this site. The other set was housed temporarily in the instrument shack, awaiting for a suitable time and opportunity to install at Pure Oil B Structure located 14,500 feet SW of A Structure.

In the process of moving the instruments from the instrument shack only minor damage resulted, most of which has already been repaired. In addition 75 feet of two conductor cable and a case for one recorder became lost or misplaced in the shuffle. It is hoped, however, that the above items may still be recovered.

2. Wave Data. The analysis of the wave records taken last summer has been completed. Of the data, only ten runs had waves of large enough magnitude to analyze reliably. The friction factors associated with the above runs have been calculated and vary between .032 to .15, with a mean at .070 and median at .064.

Very little data has been accumulated on the generation of shallow water wind waves during the winter months. This, of course, is due to the temporary, forced abandonment of the Pure Oil Site.

3. Theoretical Investigation. A theoretical investigation on the "Change in Wave Height Due to Bottom Friction, Percolation, and Refraction"

has been completed. This work was partly sponsored by the Office of Naval Research, U.S.N., and was performed jointly by C. L. Bretschneider and R. O. Reid.

The dissipation functions for bottom friction and percolation given by PUTNAM and JOHNSON and PUTNAM , respectively, have been used in the development of a general solution to the problem for (a) a bottom of constant slope and (b) a bottom of constant depth. Special solution of the general equations are also developed, from which it is possible to calculate the actual wave height as a result of a number of different combinations of bottom friction, percolation and refraction. A set of nomographs have been prepared and can readily be used to determine the energy loss of waves.

The method developed is an improvement on the method prepared by PUTNAM, in that it avoids computations by successive approximations. Consequently, the work involved in determining the energy loss of waves is greatly reduced. Furthermore, it is possible to calculate directly the friction factor from wave records at two stations along the path of wave travel.

4. Annual Technical Report. An annual technical report on wave energy loss is practically completed and will be forthcoming before 1 May 1953. The technical report consists of two parts, one on the theoretical work and one on the field work of the past twelve months.

V. Massachusetts Institute of Technology, Progress Report for Period 1 December 1952- 28 February 1953.

In the following is given the first progress report of the project as of March 1, covering the period December 1 through February 28, which from now on will be followed by others at regular intervals. (As of June 1, 1953 the equipment assembly was nearing completion and tests were expected to be under way during the summer).

A. Experimental Equipment

1. Wave Channel: The channel is part of the permanent equipment of the Hydrodynamics Laboratory. It is 30" wide, 36" deep and has a working section of 90 feet. A large steel entrance or exit tank and transition is provided at each end. The walls of the channel are of 1/2" plate glass over the whole 90 feet. The bottom is horizontal and is of 1/2" plate glass for 40 feet and of 1/4" steel plate for 10 feet and 40 feet at the upstream and downstream ends respectively. Construction of this flume has been proceeding for the past year and is now rapidly nearing completion.

2. Wave Generator: The generator proper consists of a horizontal aluminum piston with a vertical face, suspended from a rail-mounted carriage on top of the entrance tank. The carriage-piston is actuated by a cam-operated, hydraulic servomechanism and has continuously variable amplitude and frequency. When completed this generator will be, to our knowledge, the second wave generator in the United States, the amplitude

and frequency of which are continuously variable while the machine is in operation. This is an important feature when stopping a particular movable bed test.

3. Range of Operation: A maximum value chart was plotted for shallow water waves assuming sinusoidal profiles and indicates, for instance, the range of values of wave length obtainable for a given amplitude and depth within the limits of the flume geometry and the power of the generator.

4. Baffles: Plans are presently being drawn for lightweight aluminum frames to hold 6" mattresses of cinders to be used as baffles. As many of these mattresses as necessary will be lowered into the entrance tank behind the generator to absorb the energy of the waves generated by the back of the wavemaking piston.

5. Experimental Beach: Plans are at present being drawn for a hinged, adjustable slope false bottom which will support the beach material. The beach will be located on the 40 foot steel bottom section of the flume.

6. Instrumentation

a. Instrument Carriage: Complete plans have been drawn for a general purpose instrument carriage which will ride the length of the flume on rails and will provide for more convenient mounting of any one of the following instruments:

Point gage
Prandtl Pitot Tube
The capacitance type turbulence gage developed at the Hydrodynamic Laboratory
Construction of the all purpose carriage will probably not be undertaken until June 1953, since it will not be needed in the preliminary test program.

b. Photographic Equipment: It is planned to record the wave profiles and the history of their transformation by photographing through lucite grids on the wall of the channel. Three of those grids will be required. The motion of sediment and internal wave particles may also be recorded in this manner.

To perform this job, the laboratory is equipped with the following standard items:

One 16 mm. movie camera with a range of 8 to 64 exposures per second.
One 4" x 5" Graphic View Camera as well as one 35 mm. camera.
Lighting equipment consisting of one Strobotac with a range of 600 to 14,400 flashes per minute, six Strobo-Flash lamps with power packs and two photo flood lamps.
One electric timer graduated in thousandths of a second.

B. Proposed Range of Experimental Variables

1. Wave length: 1 ft. to 25 or 30 feet.
2. Amplitude : 0 to 1'.
3. Period : 1 sec to 6 sec.
4. Types of waves generated: Most of the waves will approach the beach as Stokian or Cnoidal waves, since the flume size limits the minimum practical value of λ/y obtainable to 1/2. Deep water waves can be generated, but in an extremely limited range of wave lengths and depths.
5. Beach slopes: Slopes corresponding to those most frequently found on the shores of North America have been chosen; 1 on 8 to 1 on 30.
6. Roughness: Sand sizes have been selected to correspond with the mean sand diameter found on the above range of North American beaches. Range of mean sand diameter = 0.15 mm to 0.4 mm.
7. Movable particles: It is planned to use spherical glass beads supplied by the Beach Erosion Board, in Grades No. 4 through 13 inclusive, corresponding to the roughness range given in No. 6 above.

C. Plan of Study

1. Preliminary Study; on-shore, off-shore transport:

a. Initially a beach of uniform slope covered with fixed sand grains of uniform size will be used to produce a definable roughness. A section along the center of the slope will be covered with movable particles of the same size as the fixed sand grains and a series of tests will be run where each of the variables, depth, amplitude, wave length and slope will be varied in turn. This will be done for both the smallest and largest roughness and particles size listed above and will serve a three-fold purpose:

Clearer definition of the pertinent range of the variables.

Provision of initial quantitative information as to the effect of each wave characteristic on the motion of these two sizes. This will provide an understanding of the mechanics of the transport and a more intelligent approach to the problem of selective sorting.

Perfection of experimental procedure including calibration of the wave machine.

b. This part of the program may be extended to include the complete range of particle sizes, a stabilized realistic beach profile with sand ripples and internal velocity and turbulence studies if it appears advisable at the time.

2. Study of Selective Sorting:

a. The slope will be divided into sections down the center of the flume, each section containing a large sample of particles of a uniform size. The selective sorting will than be studied statistically and an attempt made to discover the functional relationship between the variables considered with respect to sorting.

VI. Waterways Experiment Station, Vicksburg, Mississippi, Progress Report for Period ending 31 May 1953.

Wave Run-up on Shore Structures - Overtopping tests and run-up on a structure similar to the Galveston seawall, using a beach slope of 1 on 10 and 1 on 25 and a water depth of 29.5 feet involving seawall crest elevations of +3, + 6, +9, +12, +15, +18, and +21 were completed. These tests show that the run-up is higher on, and more water overtops, the curved-faced wall than the vertical wall tested previously for the same wave conditions. Overtopping and run-up tests on a smooth-faced pavement with a seaside slope of 1 on $1\frac{1}{2}$ using crown elevations of +3,+6,+9,+12, +15,+18,+21 and +24, a water depth of 29.5 feet and a beach slope of 1 on 10 were completed.

Effect of Inlets on Adjacent Beaches - Tests are being made in a basin simulating an ocean and a lagoon, which are separated by a barrier beach of sand that can be breached to reproduce the desired inlet. An automatic tide control is used to reproduce tides in the ocean part of the basin, which is also equipped with a 60-ft-long wave machine, and a circulating system to reproduce littoral currents when desired. The barrier beach is first stabilized by operating through a fixed cycle of tides, waves, etc; the desired inlet is then cut through the beach, and the same cycle of operation is repeated until the beach is again stabilized with the inlet in place. Special attention is paid to the physical and hydraulic characteristics of the inlet and the condition of the adjacent beaches. Under the first several conditions tested the inlet closed completely after a very few tidal cycles. The lagoon tidal apparatus has been adjusted so that the inlet will be kept open, and a further test is being undertaken.

VII. Beach Erosion Board, Research Division, Project Status Report for Quarter Ending 15 June 1953.

In addition to the research projects under contract to various institutions which are reported on above, the Research Division of the Beach Erosion Board is carrying out certain projects with its own facilities. The main unclassified projects were described in Vol. 6, No. 4 of the Bulletin (October 1952) and a short description of some of the work accomplished through the last quarter is given below.

Statistical Wave Data on The Great Lakes - Reports on the Lake Michigan and Lake Ontario data have gone to press and will be distributed in July as Technical Memorandums No. 36 and 37. The Lake Erie report has been completed and will go to press as Technical Memorandum No. 38 in July.

Project ESMOND - This is a new project being carried on by the North Atlantic Division for the Office, Chief of Engineers. The task assigned to the Beach Erosion Board on this study is to determine by laboratory testing, a relationship between some of the physical properties (density and viscosity) of bottom fluff material and soundings obtained therein with various shaped sounding leads. A preliminary testing of various leads has been made in clear water for calibration purposes. A 4-foot diameter sediment tank, 10 feet high has been constructed with glass side panels for use with fluff material obtained from the Delaware River. The viscosities of the various water-fluff mixtures to be tested are determined by use of a Brookfield viscometer, and the density by standard measurements. Relatively undisturbed samples of the fluff under test will be taken at various depths in the sediment tank by use of corporation cocks adapted to cylindrical tubes.

Wave Forecasting Methods - A comparison of waves forecast from a single storm in the Pacific by both the Sverdrup-Munk and the Darbyshire methods with those recorded by the University of California wave recorder at Pt. Arguello is being completed. Preliminary examination shows, for this one case, both methods to compare with the record with about the same order of error except for about 16 hour time lag obtained with the Darbyshire method.

Routine progress and analysis has been made on the other projects being carried out by the Research Division, and a three week course in wave phenomena and design techniques was given to certain District and Division personnel. Project reports on the Accuracy of Hydrographic Surveying and the Laboratory Investigation of the Vertical Rise of Solitary Waves on Impermeable Slopes, were published as Technical Memorandums 32 and 33.

BEACH EROSION STUDIES

Beach erosion control studies of specific localities are usually made by the Corps of Engineers in cooperation with appropriate agencies of the various States by authority of Section 2 of the River and Harbor Act approved 3 July 1930. By executive ruling the costs of these studies are divided equally between the United States and the cooperating agencies. Information concerning the initiation of a cooperative study may be obtained from any District or Division Engineer of the Corps of Engineers. After a report on a cooperative study has been transmitted to Congress, a summary thereof is included in the next issue of this bulletin. A summary of reports transmitted to Congress since the last issue of the Bulletin and lists of completed and authorized cooperative studies follow:

SUMMARIES OF REPORTS TRANSMITTED TO CONGRESS

OHIO SHORE LINE OF LAKE ERIE - SHEFFIELD LAKE VILLAGE TO ROCKY RIVER

The area studied is located in Loraine and Cuyahoga Counties on the south shore of Lake Erie from about 7 to 22 miles west of Cleveland Harbor, Ohio. It lies between Sheffield Lake Road in Sheffield Lake Village and the mouth of Rocky River, a distance of about 15 miles. Lorain and Cuyahoga Counties, including the city of Cleveland had a total population of about 1,500,000 in 1950. The city of Rocky River and lake front villages have a combined population of about 20,000. There is little seasonal change in population of these areas. The property along the shore line of the study area has been developed mainly for private residential purposes. The shore is publicly owned at the Avon Lake Village Waterworks, at Huntington and Rocky River Parks and at a number of small village parks. Narrow beaches existing at some of these parks are used for recreational purposes.

The shore line of the study area consists of nearly vertical bluffs from 20 to 60 feet in height. The surface stratum is composed generally of boulder clay. The lower part of the bluffs exposed to wave action is shale for most of the shore frontage of the area. There are few beaches because of the small proportion of sand in the eroding bluffs and because no material reaches the shore from other sources. Miscellaneous groins and walls have been constructed in an attempt to prevent erosion of the shore. Groins have been ineffective due to scarcity of littoral drift, except where the bluffs are composed of unconsolidated material. West of Avon Point the predominant direction of the minor littoral drift is westward, east of that point, except in the city of Rocky River, it is eastward, as indicated by accretion at groins. In Rocky River a slightly greater amount of material east of groins is indicative of a slight westward predominance of drift.

The mean lake level for the months of March to December is about 1.6 feet above the established low water datum. The highest lake stage and the highest monthly mean stage recorded at Cleveland, Ohio, are respectively 5.25 and about 4 feet above low water datum. Storms cause

changes in lake levels as winds move the water toward the ends of the lake. Of winds which generate waves affecting the area, those from the northeasterly quadrant have the greatest fetch, about 150 miles. Those from the northwesterly quadrant apparently have an approximately equal effect on material movement, as the predominant direction of drift is eastward on the shore having a northwest-southeast orientation and westward on shores having a northeast-southwest orientation. It is estimated that, considering the effect of wind-set-up during easterly storms to be about 1/2 foot, the lake could reach a level in the study area of about 4.5 feet above low water datum. During severe storms waves may range up to 12.5 feet in height in deep water, but ordinarily waves of this height would break before reaching the shore structure. The maximum height of waves breaking landward of the low water datum shore line at a design lake stage of 4.5 above low water datum would be about 3.5 feet. Existing beaches have been preserved by groin systems. Any new beach development would require artificial placement of fill and its retention by a groin system. In those areas where no beach presently exists and none is desired, the bluff may be protected by a seawall with top elevation of 8 feet above low water datum and the slope above armored with stone revetment to elevation 12 feet above low water datum. If the bluff above the revetment is graded to a stable slope, so that slumping thereof would not cause a horizontal thrust against the revetment, protection can also be provided by a continuous belt of heavy riprap at the toe of the bluff extending up to elevation 12 feet above low water datum. Ice forms a protective coating over beaches during winter months, but the lifting and battering actinn of shifting ice floes during the spring breakup must be considered in designing shore structures for structural stability.

The division and district engineers and Beach Erosion Board have developed plans for protecting and improving the shores of the study area. They concluded that there is an insufficient natural supply of beach material to provide beaches of the minimum width necessary to protect the bluffs from erosion by wave action for the greater part of the study area and that the most practicable general plan of protection of the shore line consists of some type of seawall or revetment. They also concluded that if additional beach is desired, the plan would consist of artificial placement of fill and groins to retain the fill. They further concluded that for the publicly owned shores, ho additional protection is required or that the protective benefits of the considered work are not sufficient to make the project eligible for Federal participation under existing laws. They recommended that owners of private property adopt the plan of improvement considered best suited to local conditions and the desired use of the property, and that continuous sections of shore be protected at one time wherever possible to prevent flanking of isolated improved sections. They recommended no Federal participation in the cost of any of the proposed improvements.

In accordance with existing statutory requirements, the Board stated its opinion that:

a. It is not advisable for the United States to adopt a project at this time authorizing Federal participation in the cost of protecting and improving the Lake Erie shore of Ohio within the area studied;

b. No public interest is involved in the proposed improvements; and

c. No share of the expense should be borne by the United States.

The Chief of Engineers concurred in the foregoing conclusions and recommendations.

OCEAN CITY, NEW JERSEY

Ocean City is located on the coast of New Jersey about 35 miles northeast of Cape May, the southern tip of the State at the entrance to Delaware Bay. It comprises the entire length of the barrier beach island 8 miles long known as Peck Beach. Great Egg and Corsons Inlets are respectively the northeastern and southwestern boundaries of the city and island. The northeastern one-third of the island is the most developed portion. The total patronage of the resort is estimated at 500,000 annually. The summer residents are estimated at 75,000, compared to the permanent population 5,950. Summer weekend vacationists are estimated at 20,000. The assessed valuation of property in the city in 1949 was nearly $17,000,000. About 36 percent of the ocean beach is owned by the city and the remainder is privately owned. Between Surf Road and 12th Street the city owns 31.7 percent of the shore frontage.

The ocean tides at Ocean City are semi-diurnal, the mean range being 4 feet and the spring range 5 feet. Tides exceeding 7 feet above mean low water are rare. The maximum height of waves observed just offshore was 8 feet. The direction of approach of waves close to shore is such that littoral drift northeast of North Street is toward the inlet and southwest of 5th Street is southwestward. The predominant direction of drift in southern New Jersey is southerly, the apparent source of beach material to the area being adjacent portions of the barrier beach to the northeast. The rate of movement of material across Great Egg Inlet has been irregular. Progressive improvements in the inlet region have restricted the normal tendency of the inlet to migrate, resulting in a change in the supply of material moving into the problem area. The direction and intensity of wave action, as governed by bottom configuration, and the paths of tidal currents, have become more restricted in zone of shore influence due to limitations of former variability of channel location. The deficiency in supply, averaging about 50,000 cubic yards annually over the period from 1930 to 1950, resulted in recession of the shore line so that the high water line at the time of the study, was generally under or landward of the boardwalk as far south as 12th Street. A groin system probably retarded the erosion to some extent, but the beaches were unsatisfactory.

The district engineer developed a plan for protecting and improving the shores, comprising restoration of the beach to a width of 300 feet between the boardwalk or bulkhead and the high water line by artificial deposit of sand, and stone extensions of 7 existing groins, and made an economic analysis of proposed protective measures. He found that the benefits from prevention of damages, increased earning power of land and recreational benefits of the proposed work warrant the adoption of the project of protection and improvement. He concluded that the public interest therein warrants Federal participation to the extent of one-third of the cost applicable to the publicly owned shore in accordance with the policy established by Public Law 727, 79th Congress. The division engineer concurred in the views and recommendations of the district engineer.

The Beach Erosion Board concurred in the opinion of the reporting officers that the prospective benefits warrant the expenditure for suitable protective and improvement measures. In accordance with existing statutory requirements, the Board stated its opinion that:

a. It is advisable for the United States to adopt a project authorizing Federal participation in the cost of protecting and improving the shore of Ocean City, New Jersey;

b. The public interest involved in the proposed improvement is substantial. It is associated with prevention of damages to public property and recreational benefits to the general public; and

c. The share of the expense which should be borne by the United States is one-third of the first cost of the work applicable to the publicly owned shore. The estimated amount of this share is $199,000 (10.6 percent of the first cost), based on present public ownership of 31.7 percent of the shore frontage involved in the project.

The Beach Erosion Board recommended that a project be adopted by the United States authorizing Federal participation, subject to certain conditions, by the contribution of Federal funds in an amount equal to one-third of the first costs of the measures for the protection and improvement of the publicly owned portions of the shores of Ocean City, New Jersey, from Surf Road to 12th Street, under a plan for the entire shore within those limits comprising artificial placement of suitable sand fill in amount of approximately 1,900,000 cubic yards on the ocean shore to widen the beach to a width of approximately 300 feet seaward of the boardwalk or bulkhead to the mean high water line, and extension of 7 existing stone groins as deferred construction when experience indicates the need thereof.

The Chief of Engineers concurred in the recommendations of the Beach Erosion Board.

VIRGINIA BEACH, VIRGINIA

Virginia Beach is located on the east coast of Virginia about 19 miles east of Norfolk and 3.5 miles south of Cape Henry, which is the south point of the entrance to Chesapeake Bay. The shore frontage of the city is 3-1/3 miles long. The city is extensively developed as a residential and resort area. It has a permanent population of 5,300 and a maximum summer population of about 45,000. A combined concrete promenade and light seawall 1.93 miles long built in 1927 is owned by the city. The shore frontage is owned principally by the city. The United States owns a frontage of 205 feet, the site of a Coast Guard Station. The remainder, less than 5 percent is privately owned.

The tides in the ocean at Virginia Beach are semi-diurnal, the mean range being 3 feet and the spring range 3.6 feet. The maximum storm tide of record was about 7 feet above mean high water, but tides greater than 3 feet above mean high water are infrequent. Statistical data on ocean swells off Virginia Beach indicate that the predominant direction of high swells is from the northeast and east. Refraction effects of the offshore bottom and effects of the tidal currents due to the proximity of the entrance to Chesapeake Bay influence the wave pattern, so that the littoral characteristics cannot be determined from existing data. There is evidence of seasonal reversals in direction of drift, but no evidence that there is a predominant drift of appreciable volume in either direction. The beach is composed of medium sand and the offshore bottom of fine sand. The effect of major storms appears to be a temporary shifting of foreshore material to the offshore area. The required protection to the seawall and upland can be provided by a beach of sufficient height and width so that it will not be entirely removed during one storm period. Shore line recession during the 1927 and 1948 storms indicates that an artificially placed beach of suitable material with a minimum berm width of 100 feet at an elevation of 7 feet above mean low water would be satisfactory for this purpose. Material is restored to the foreshore during the adjustment period following such storms, but presumably part of the material is not returned and consequently the shore line gradually recedes. The low rate of loss indicates that a restored beach may be economically maintained by artificial replenishment as needed. As available data are inadequate to determine whether groins would effect lower annual costs, it is advisable to include them in the plan of protection for deferred construction if needed.

The district engineer developed a plan for protecting and improving the shores, and made an economic analysis of proposed protective measures. He found that the benefits from prevention of damages, increased earning power of land and property, and recreational benefits of the proposed work warrant the adoption of the project of protection and improvement. He concluded that the public interest therein warrants Federal participation to the maximum extent permissible under the policy established by Public Law 727, 79th Congress.

The division engineer concurred in the conclusions and recommendations of the district engineer.

The Beach Erosion Board concurred in the opinion of the reporting officers that the prospective benefits warrant the expenditure for suitable protective and improvement measures, and the Board recognized the feasibility of providing the protective beach, within the limitations imposed by the general plan, either by direct placement along the entire frontage in one operation, or by placement of material initially in the southern section and subsequently at strategic locations, to be distributed by natural processes.

In accordance with existing statutory requirements the Board stated its opinion that:

a. It is advisable for the United States to adopt a project authorizing Federal participation in the cost of protecting and improving the shore of Virginia Beach, Virginia;

b. The public interest involved in the proposed improvement is substantial. It is associated with prevention of damages to public property and recreational benefits to the general public; and

c. The share of the expense which should be borne by the United States is the portion of the cost applicable to protecting the Federally owned frontage plus one-third of the first cost of measures for the restoration and protection of the other publicly owned portions of the shore of Virginia Beach. The estimated amount of this share is $377,000 for the fill and $298,000 additional for deferred groin construction.

The Board recommended that a project be adopted by the United States authorizing Federal participation, subject to certain conditions, by the contribution of Federal funds in an amount equal to the portion of the cost applicable to protecting the Federally owned frontage plus one-third of the first cost of the measures for the restoration and protection of the other publicly owned portions of the shore of Virginia Beach, Virginia, under a plan for the entire shore within the city limits comprising artificial placement of suitable sand fill in amount of approximately 1,100,000 cubic yards on the ocean shore to widen the beach berm to a minimum width of approximately 100 feet at elevation 7 feet above mean low water and construction of a system of approximately 21 groins as deferred construction when experience indicates the need thereof.

The Chief of Engineers concurred with the recommendations of the Beach Erosion Board.

OHIO SHORE LINE OF LAKE ERIE - SANDUSKY BAY

The area studied comprises the easterly 2 miles of Townsend Township located in Sandusky County on the south shore of the westerly part of Sandusky Bay. It is located about 10 miles west of the city of Sandusky,

Ohio. Sandusky Bay is located on the south shore of Lake Erie about midway between Toledo and Cleveland. Its entrance and eastern end have been improved by the United States for navigation. Sandusky County had a population of 43,152 in 1950. The city of Sandusky and Erie County exclusive of that city had populations of 29,060 and 23,102 respectively. The property along the shore line of the study area is devoted mainly to agriculture, but some summer homes have been built along the shore. Inland areas are devoted principally to the agricultural uses. The shore in the study area is all privately owned.

Sandusky Bay is a shallow body of water almost completely land locked, and connected to Lake Erie at its eastern end. Sandusky River drains into the bay at its western end. The shore line of the study area consists of eroding bluffs of lacustrine clay, rising to a height of about 8 feet above low water datum, with little or no beach fronting the bluffs. It has been estimated that only about 14 percent of the material in the upper 3 feet of the bluffs is coarser than silt. From the toe of the bluff, beach and offshore bottom slopes are very flat, as is also the adjacent topography at the top of the bluff. No protective structures have been constructed in the study area, but a stone dike was constructed in 1948 to protect a low marshy area about one mile east of the study area. Small quantities of accretion on the east sides of small impermeable boat landings along the shore line in areas adjacent to the study area indicate a tendency for the small quantity of material available to move westward.

The mean level of Lake Erie for the months of March to December is about 1.6 feet above the established low water datum. The highest lake stage and the highest monthly mean recorded at Cleveland, Ohio, are respectively 5.25 and about 4 feet above low water datum. The average water levels of Sandusky Bay and Lake Erie are approximately the same over a period of time, but for Lake level changes of short duration the bay level fails to reach the extreme of the lake level due to its narrow entrance. During severe northeasterly storms, the bay could infrequently reach a level in the study area of about 5 feet above low water datum. Due to the shallow depth of the bay under normal conditions, waves seldom exceed $2\frac{1}{2}$ feet. The maximum wave height that need be considered in designing structures where no protective beach exists is probably 2 feet. At low lake levels the flat slope of the bay bottom and the foreshore protect the bluffs from erosion by wave action, but with higher levels of water in the bay, waves reach and break directly against the bluff. Most of the material eroded from the bluffs, due to its fineness, is apparently deposited offshore by wave action. Consequently, little beach building material is available for transport by littoral forces. Erosion of the bluffs can be arrested by sloping the bluffs and armoring them with wave resistant material.

The district and division engineers, and the Beach Erosion Board concluded that the most practical and economical method of protecting the shores of Sandusky Bay within the study area is by grading the existing vertical bluff and placing quarry-run stone on a filter blanket of crushed

stone from the toe of the bluff to its top at elevation 8 feet above low water datum, and that no public interest is involved in the considered plan of improvement, since there is no publicly owned property within the area studied. They recommended that protective measures which may be undertaken from time to time by local interests, based on their own determination of economic justification be accomplished in accordance with the plan for stone revetment proposed in the report. They further recommended that continuous sections of shore be protected at one time, where possible, to take advantage of the saving in construction costs, as well as to prevent flanking of the protective works where adjacent unprotected frontage would continue to erode.

In accordance with existing statutory requirements, the Board stated its opinion that:

a. It is not advisable for the United States to adopt a project authorizing Federal participation in the cost of protecting and improving the shore of Ohio within the area studied;

b. No public interest is involved in the proposed improvements; and

c. No share of the expense should be borne by the United States.

The Chief of Engineers concurred in the foregoing conclusions and recommendations.

COMPLETED COOPERATIVE BEACH EROSION STUDIES

LOCATION	COMPLETED	PUBLISHED IN HOUSE DOC.	PUBLISHED IN CONGRESS
MAINE			
Old Orchard Beach	20 Sep 35		
NEW HAMPSHIRE			
Hampton Beach	15 Jul 32		
MASSACHUSETTS			
South Shore of Cape Cod (Pt. Gammon to Chatham)	26 Aug 41		
Salisbury Beach	26 Aug 41		
Winthrop Beach	12 Sep 47	764	80
Lynn-Nahant Beach	20 Jan 50	134	82
Revere Beach	12 Jan 50	167	82
Nantasket Beach	12 Jan 50		
Quincy Shore	2 May 50	145	82
Plum Island	18 Nov 52		
RHODE ISLAND			
South Shore (Towns of Narragansett, South Kingstown, Charlestown & Westerly)	4 Dec 48	490	81
CONNECTICUT			
Compo Beach, Westport	18 Apr 35	239	74
Hawk's Nest Beach, Old Lyme	21 Jun 39		
Ash Creek to Saugatuck River	29 Apr 49	454	81
Hammonasset River to East River	29 Apr 49	474	81
New Haven Hbr. to Housatonic R.	29 Jun 51		
Conn. River to Hammonasset R.	28 Dec 51	514	82
Pawcatuck River to Thames River	31 Mar 52	31	83
Niantic Bay to Conn. River	11 Jul 52	84	83
Housatonic R. to Ash Creek	12 Mar 53		
NEW YORK			
Jacob Riis Park, Long Island	16 Dec 35	397	74
Orchard Beach, Pelham Bay, Bronx	30 Aug 37	450	75
Niagara County	27 Jun 42	271	78
South Shore of Long Island	6 Aug 46		

NEW JERSEY

Manasquan Inlet & Adjacent Beaches	15 May 36	71	75
Atlantic City	11 Jul 49	538	81
Ocean City	15 Apr 52		

VIRGINIA

Willoughby Spit, Norfolk	20 Nov 37	482	75
Colonial Beach, Potomac River	24 Jan 49	333	81
Virginia Beach	25 Jun 52		

NORTH CAROLINA

Fort Fisher	10 Nov 31	204	72
Wrightsville Beach	2 Jan 34	218	73
Kitty Hawk, Nags Head & Oregon Inlet	1 Mar 35	155	74
State of North Carolina	22 May 47	763	80

SOUTH CAROLINA

Folly Beach	31 Jan 35	156	74
Pawleys Is., Edisto Beach and Hunting Island.	24 Jul 51		

GEORGIA

St. Simon Island	18 Mar 40	820	76

FLORIDA

Blind Pass (Boca Ciega)	1 Feb 37	187	75
Miami Beach	1 Feb 37	169	75
Hollywood Beach	28 Apr 37	253	75
Daytona Beach	15 Mar 38	571	75
Bakers Haulover Inlet	21 May 45	527	79
Anna Maria & Longboat Keys	12 Feb 47	760	80
Jupiter Island	13 Feb 47	765	80
Palm Beach (1)	13 Feb 47	772	80
Pinellas County	22 Apr 53		

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(1) A cooperative study of experimental steel sheet pile groins was also made, under which methods of improvement were recommended in an interim report dated 19 Sep 1940. Final report on experimental groins was published in 1948 as Technical Memo. No. 10 of the Beach Erosion Board.

MISSISSIPPI

Hancock County	3 Apr 42		
Harrison County - Initial	15 Mar 44		
Harrison County - Supplement	16 Feb 48	682	80

LOUISIANA

Grand Isle	28 Jul 36	92	75

TEXAS

Galveston (Gulf Shore)	10 May 34	400	73
Galveston Bay, Harris County	31 Jul 34	74	74
Galveston (Gulf Shore)	5 Feb 53		
Galveston (Bay Shore)	23 Jun 53		

CALIFORNIA

Santa Barbara - Initial	15 Jan 38	552	75
Supplement	18 Feb 42		
Final	22 May 47	761	80
Ballona Creek & San Gabriel River (Partial)	11 May 38		
Orange County	10 Jan 40	637	76
Coronado Beach	4 Apr 41	636	77
Long Beach	3 Apr 42		
Mission Beach	4 Nov 42		
Pt. Mugu to San Pedro BW	27 Jun 51		
Carpinteria to Pt. Mugu	4 Oct 51	29	83

PENNSYLVANIA

Presque Isle Peninsula, Erie (Interim)	3 Apr 42		
(Final)	23 Apr 52		

OHIO

Erie County - Vicinity of Huron	26 Aug 41	220	79
Michigan Line to Marblehead	30 Oct 44	177	79
Cities of Cleveland & Lakewood	22 Mar 48	502	81
Chagrin River to Fairport	22 Nov 49	596	81
Vermilion to Sheffield Lake Village	24 Jul 50		
Fairport to Ashtabula	1 Aug 51	351	82
Ashtabula to Penna. State Line	1 Aug 51	350	82
Sandusky to Vermilion	7 Jul 52	32	83
Sandusky Bay	31 Oct 52		
Sheffield Lake Village to Rocky River	31 Oct 52		
Euclid to Chagrin River	18 Jun 53		

	ILLINOIS		
State of Illinois	8 Jun 50	28	83
	WISCONSIN		
Milwaukee County	21 May 45	526	79
Racine County	5 Mar 52	88	83
	PUERTO RICO		
Punta Las Marias, San Juan	5 Aug 47	769	80
	HAWAII		
Waikiki Beach	5 Aug 52		

AUTHORIZED COOPERATIVE BEACH EROSION STUDIES

NEW HAMPSHIRE

HAMPTON BEACH. Cooperating Agency: New Hampshire Shore and Beach Preservation and Development Commission

Problem: To determine the best method of preventing further erosion and stabilizing and restoring the beaches, also to determine the extent of Federal aid in any proposed plans of protection and improvement.

MASSACHUSETTS

PEMBERTON POINT TO GURNET POINT. Cooperating Agency: Department of Public Works.

Problem: To determine the best methods of shore protection, prevention of further erosion and improvement of beaches, and specifically to develop plans for protection of Crescent Beach, the Glades, North Scituate Beach and Brant Rock.

CONNECTICUT

STATE OF CONNECTICUT. Cooperating Agency: State of Connecticut (Acting through the Flood Control and Water Policy Commission)

Problem: To determine the most suitable methods of stabilizing and improving the shore line. Sections of the coast are being studied in order of priority as requested by the cooperating agency until the entire coast has been included.

NEW YORK

N.Y. STATE PARKS ON LAKE ONTARIO. Cooperating Agency: Department of Conservation, Division of Parks.

Problem: To determine the best method of providing and maintaining certain beaches and preventing further erosion of the shores at Selkirk Shores, Fair Haven Beach and Hamlin Beach State Parks, and the Braddock Bay area owned by the State of New York.

NEW JERSEY

STATE OF NEW JERSEY: Cooperating Agency: Department of Conservation and Economic Development.

Problem: To determine the best method of preventing further erosion and stabilizing and restoring the beaches, to recommend remedial measures, and to formulate a comprehensive plan for beach preservation or coastal protection.

NORTH CAROLINA

CAROLINA BEACH. Cooperating Agency: Town of Carolina Beach

Problem: To determine the best method of preventing erosion of the beach.

ALABAMA

PERDIDO PASS AND ALABAMA POINT. Cooperating Agency: Alabama State Highway Department.

Problem: To determine the best method of preventing further erosion of Alabama Point, for stabilizing the inlet, and for determining the extent of Federal aid, if any, in the cost of such proposed plans for protection and improvement as may be recommended.

CALIFORNIA

STATE OF CALIFORNIA. Cooperating Agency: Division of Beaches and Parks, State of California.

Problem: To conduct a study of the problems of beach erosion and shore protection along the entire coast of California. The current study covers the Santa Cruz area.

WISCONSIN

KENOSHA. Cooperating Agency: City of Kenosha.

Problem: To determine the best method of shore protection and beach erosion control.

TERRITORY OF HAWAII

WAIMEA & HANAPEPE , KAUAI. Cooperating Agency: Board of Harbor Commissioners, Territory of Hawaii

Problem: To determine the most suitable method of preventing erosion, and of increasing the usable recreational beach area, and to determine the extent of Federal aid in effecting the desired improvement.